Priority micronutrient density in foods

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Article

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Abbreviations:
ARs: Average requirements
DGLVs: Dark green leafy vegetables
EFSA: European Food Safety Authority
FCTs: Food composition tables
FDC: FoodData Central
HICs: High-income countries
LMICs: Low- and middle-income countries
NCDs: Non-communicable diseases
UPFs: Ultra-processed foods
WRA: Women of reproductive age

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval

Abstract

Background: Despite concerted efforts to improve diet quality and reduce malnutrition, micronutrient deficiencies remain widespread globally, especially in low- and middle-income countries and among population groups with increased needs, where diets are often inadequate in iron, zinc, folate, vitamin A, calcium, and vitamin B_{12}. There is a need to understand the density of these micronutrients and their bioavailability across diverse foods and the suitability of these foods to help meet requirements for populations with high burdens of micronutrient malnutrition.

Objective: We aimed to identify the top food sources of these commonly lacking micronutrients, which are essential for optimal health, to support efforts to reduce micronutrient malnutrition among various populations globally.

Methods: We built an aggregated global food composition database and calculated recommended nutrient intakes for five population groups with varying requirements. An approach was developed to rate foods according to their density in each and all priority micronutrients for various population groups with different nutrient requirements.

Results: We find that the top sources of priority micronutrients are organs, small fish, dark green leafy vegetables, bivalves, crustaceans, goat, beef, eggs, milk, canned fish with bones, lamb, and mutton. Cheese, goat milk, and pork are also good sources, and to a lesser extent, yogurt, fresh fish, pulses, teff, and canned fish without bones.

Conclusions: The results provide insight into which foods to prioritize to fill common micronutrient gaps and reduce undernutrition.

Keywords: nutrient density, micronutrient deficiencies, animal-source foods, organs, shellfish, fish, dark green leafy vegetables, ruminant meat, eggs, dairy

Introduction

Food is integral to everyday life, providing essential energy and nutrients for human function. An important aspect of food, among others, is the vitamins and minerals it provides. Yet in many low- and middle-income countries (LMICs) diets are known to be lacking in micronutrients, especially for population groups with increased needs, leading to deficiencies, particularly in iron, zinc, folate, vitamin A, calcium, and vitamin B_{12} (hereafter referred to as "priority micronutrients"), that can have severe and lasting effects (1–6). Even in high-income countries (HICs) like the United States, micronutrient deficiencies such as iron deficiency may be common, especially among women (7). Globally, current diets are failing to provide adequate density of these essential micronutrients.

There is an urgent need, therefore, to increase the density of priority micronutrients in diets globally. One efficient and cost-effective strategy for reducing micronutrient deficiencies in LMICs is food fortification (8). However, there are more than 70,000 compounds in foods (9) bound together in a food matrix, which synergistically impact metabolism, including nutrient absorption, and may have beneficial effects on satiety and the immune system, offering protection from disease, among other potentially important health implications (10–13). Thus, fortifying staple foods with priority micronutrients is important but does not fully replicate inherently nutrient-dense foods and their health effects. Obtaining adequate micronutrients from minimally processed foods may have additional benefits beyond fortification due to the added value of diverse synergistic nutrients within a food matrix (10–12). Moreover, while there is large variation in the health effects of different foods and dietary patterns, energy-dense ultra-processed foods (UPFs) in particular are associated with numerous noncommunicable diseases (NCDs) and mortality and are increasing rapidly in LMICs (14). Energy-dense ultra-processed foods are generally hyper palatable which can lead to overconsumption and weight gain when they are a predominant component of the food environment (15). Improving overall diet quality, especially the quantity and diversity of minimally processed foods inherently dense in priority micronutrients is crucial to reduce micronutrient malnutrition while minimizing the transition to UPFs and potential associated increase in NCDs.

Our study aims to identify the top food sources of commonly lacking micronutrients, which are essential for optimal health, to support efforts to reduce micronutrient malnutrition among various populations globally, particularly in low- and middle-income countries.

Methods

Recommended nutrient intakes. We calculated recommended intakes for adults ≥ 25 years of age and groups vulnerable to malnutrition, including children 2–4 years, adolescents, non-pregnant and non-lactating women of reproductive age (WRA), and pregnant women, from the European Food Safety Authority (EFSA) (16) for vitamin A, folate, calcium, and zinc and from the Institute of Medicine (17) for vitamin B_{12} and iron. This aligns with the recently proposed harmonized nutrient reference values (18), except for iron, because EFSA values are based on the assumption that the population has iron stores, which is not the case for many people in LMICs. We used recommended nutrient intakes rather than average requirements because we are interested in target values for individuals, not in estimating population level adequacy.

Building a global food composition database. We built a global food composition database (excluding fortified foods), with values for calories, phytate (19), and six priority micronutrients: vitamin A, folate, vitamin B_{12}, calcium, iron, and zinc. Nutrient densities are from USDA FoodData Central (FDC) (20) and national and regional food composition tables (FCTs) from LMICs globally (21): Kenya, Malawi, and Western Africa (Sub-Saharan Africa); Bangladesh, Indonesia, Laos, Vietnam, and ASEAN (South and South-East Asia); Mexico and Colombia (Latin America).

Foods were aggregated when showing relatively low nutrient density variance (for example, pulses) or when likely to be targeted as a food group in policy and programming (for example, DGLVs). Global nutrient values for individual foods were obtained by calculating medians of composite values from the selected FCTs. Composite values were obtained by averaging nutrient values for different cooking methods (and/or raw foods) and/or different cuts of a given food for meat. Global nutrient values for aggregated food groups were obtained by averaging composite values at the regional level and from FDC. Composite values for a given region were obtained by calculating the medians of nutrient values for several individual foods within a food group, available in the selected FCTs corresponding to that region. Standard deviations were calculated for all obtained global nutrient values, as a measure of variability across included FCTs.

We accounted for iron and zinc bioavailability. For iron, foods were classified into one of three levels of iron absorption (20% for ruminant meat, 15% for all other animal-source foods, and 10% for all plant-source foods), based on the proportion of heme to non-heme iron contained (1): 68% heme-iron in ruminant meat, including beef (22–24), goat, and lamb/mutton (24,25); 39% heme-iron in pork (23,24,26–28); 26% heme-iron in chicken (23,24,26–28), fish and seafood (23,26–29), and eggs and dairy (27); and 40% heme-iron in all other meat, including offal (22,27,28). Regarding zinc, foods were classified into one of four levels of zinc absorption (44%, 35%, 30%, and 26%), based on the amount of phytate contained in each food in a portion equivalent to one-third of daily mass intake, assuming an energy density of 1.3 kcal/g and considering average requirements for energy for a moderately active WRA (16) (see Supplemental Material for details).

Priority micronutrient density rating. Foods were classified into one of four levels of micronutrient density based on the calories and grams needed to provide one-third (for individual nutrients) or an average of one-third (for the aggregate score) of recommended intakes of vitamin A, folate, vitamin B_{12}, calcium, iron, and zinc. For the aggregate score, the average share of recommended intakes (*ASRI*) across the six micronutrients (*A*), for a given quantity of calories and grams (*i*), of a given food (*j*), was calculated as:

$$ASRI_{i,j} = \frac{1}{|A|} \sum_{a \in A} \min \left\{ \frac{nutrient\_density_{a,j} * i}{recommended\_intakes_a}, 1 \right\}$$

A similar approach was previously used to identify micronutrient-dense complementary foods for young children (4,30). Ratings were calculated for different population groups according to the following thresholds for Average Requirements (ARs) of energy for a moderately active individual and hypothetical ARs for mass, assuming an energy density of 1.3 kcal/g (the mean energy density of a minimally processed plant-based, low-fat diet and animal-based, ketogenic diet (31)):

- Very high: ≤ one-sixth of ARs for both energy and mass
- High: ≤ one-third of ARs for both energy and mass and < one-sixth of ARs for either energy or mass
- Moderate: ≤ one-third and > one-sixth of ARs for both energy and mass
- Low: > one-third of ARs for either energy or mass

Micronutrient density of milk was classified based solely on ARs for energy, since mass is typically not a limiting factor for liquids. The same energy thresholds as for solid foods were used for very high and low micronutrient density. For high micronutrient density, thresholds were ≤ one-fourth and > one-sixth of ARs for energy. For moderate micronutrient density, thresholds were ≤ one-third and > one-fourth of ARs for energy.

As indicated in the formula for the aggregate score, each micronutrient's contribution was capped at 100% of recommended intakes, which means that each micronutrient can contribute nothing or up to one-half of the total score (4,30). To illustrate this, a food containing only two of the six nutrients would provide 100% of recommended intakes of both nutrients, while a food with a perfectly even proportion of recommended intakes across all six nutrients would provide 33.3% of recommended intakes of all six nutrients—each micronutrient thus contributing an equal one-sixth of the total score. This approach ensures that for foods to rate high, they need to be high in at least two micronutrients and that foods with very high densities of individual micronutrients are not rated higher for providing amounts well above recommended intakes or above upper limits.

Results

Recommended nutrient intakes. Recommended nutrient intakes vary by population and, for iron and zinc, bioavailability (Table 1). Among groups with roughly similar ARs for energy, recommended nutrient intakes are generally highest for pregnant women, followed by adults, WRA, and adolescents, but there is variability by nutrient. Notably, recommended folate intake for pregnant women is double than for adults, WRA, and adolescents; recommended iron intake for pregnant women is more than triple than for adults, more than double than for adolescents, and more than 50% higher than for WRA. Recommended intakes for vitamin A, vitamin B_{12}, calcium, and zinc vary less across these groups.

Global food composition database. Table 2 shows the compiled global food composition database of 41 individual and aggregate foods, with values for the six priority micronutrients, energy, phytate, and iron and zinc bioavailability (a version of the global food composition database which includes standard deviations is available in Supplemental Table 1). Interestingly, some food groups showed high nutrient density variance across included foods, such as DGLVs, with spinach, amaranth leaves, and cassava leaves having much higher values than lettuce and cabbage (Supplemental Table 4). Similarly, hard cheese (for example, cheddar and aged goat cheese) and fatty fish (for example, herring and mackerel) were more nutrient-dense than soft cheese (for example, cottage cheese) and lean fish (for example, cod and tilapia), respectively (Supplemental Table 6). Other food groups, such as pulses, presented more equal nutrient density distributions across foods, but there were significant differences across FCTs (Supplemental Tables 2–7). For instance, Sub-Saharan Africa and South/South-East Asia showed much lower values for folate in pulses than Latin America and FDC, which may be due to different varieties, culinary traditions, and cooking methods and times.

Aggregate micronutrient density scores for WRA. We emphasize the results for WRA in the main text because they are the largest population group, > 1.8 billion globally, that is at increased risk for micronutrient malnutrition. The quantity of calories and grams required to provide an average of one-third of recommended intakes for WRA of vitamin A, folate, vitamin B_{12}, calcium, iron, and zinc varies widely by food (**Figure 1**). Foods with very high aggregate micronutrient density for WRA include organs (liver, spleen, kidney, and heart from beef, goat, lamb, chicken, and pork), small dried fish, DGLVs, bivalves (clams, mussels, and oysters), crustaceans, goat, beef, eggs, milk, canned fish with bones, lamb/mutton, and cheese. Foods with a high aggregate micronutrient density include goat milk and pork. Foods with a moderate aggregate micronutrient density include yoghurt, fresh fish (including different species of marine and freshwater fish), pulses, and teff. All other foods included in the analysis scored as having low aggregate micronutrient density for WRA.

Individual micronutrient density scores for WRA. Bivalves are the only food to contain at least a moderate density of all six micronutrients for WRA—they contained a very high density (hereafter referred to as "top sources") of all micronutrients except for folate, for which they contain a moderate density (**Figure 2**). Most animal-source foods and DGLVs were top sources of two or more micronutrients. All foods contained at least a moderate density of at least one of the six micronutrients except for other vegetables; roots, tubers, and plantains; nuts; and refined grain products.

Top iron sources included organs, bivalves, small dried fish, goat, and teff, each providing one-third of recommended iron intakes with less than one-sixth of ARs for energy and hypothetical ARs for mass (Figure 2 and **Figure 3**). Top zinc sources included organs, bivalves, crustaceans, goat, beef, eggs, canned fish with bones, lamb/mutton, cheese, and pork (Figure 2). Top vitamin A sources included liver (including beef, goat, lamb, chicken, and pork liver), small dried fish, DGLVs, bivalves, eggs, cow milk, cheese, and vitamin A-rich fruits and vegetables. Top calcium sources included small dried fish, DGLVs, bivalves, cow milk, canned fish with bones, cheese, goat milk, and yogurt. Top folate sources included liver, DGLVs, eggs, pulses, and quinoa. Finally, top vitamin B_{12} sources included organs, small dried fish, bivalves, crustaceans, ruminant meat, eggs, milk, cheese, canned fish, pork, yogurt, and fresh fish.

Aggregate micronutrient density scores for other population groups. Micronutrient density scores may vary depending on the population, given differences in recommended nutrient intakes. The aggregate micronutrient density ratings remained similar for all other groups, with a few exceptions (**Figure 4 and 5**; Supplementary Figures 1–6). Organs, small dried fish, DGLVs, shellfish, beef, goat, eggs, cow milk, canned fish with bones, and lamb/mutton all remained with a rating of very high aggregate micronutrient density. Cheese rated very high for children 2–4 years, adolescents, WRA, and pregnant women but high for adults. Notably, vitamin A-rich fruits and vegetables and seeds rated high for children 2–4 years but low for all other groups. Canned fish without bones rated moderate for children 2–4 years, adolescents, and adults but low for WRA and pregnant women. Quinoa rated moderate for children 2–4 years and adolescents but low for all other groups. Finally, teff rated low for pregnant women but moderate for all other groups.

Individual micronutrient density scores for other population groups. There were many differences in ratings for specific micronutrients depending on the population, especially for iron and folate (Figure 5 and **Figure 6**; Supplementary Figures 4–6). Organs, bivalves, small dried fish, and goat were the only foods that rated as top iron sources for all population groups. For iron, DGLVs rated low for pregnant women but high for all other groups, while crustaceans rated low for pregnant women, moderate for children 2–4 years and WRA, and high for adolescents and adults. Beef was a top source of iron for children 2–4 years, adolescents, and adults but rated high for WRA and pregnant women. For adults, teff, fonio, sorghum, pulses, and millet were all top iron sources, whereas they all rated low for pregnant women, except for teff and fonio, which rated moderate. Further, quinoa, canned fish with bones, eggs, seeds, and pork also rated high for iron for adults, while they rated moderate (quinoa, canned fish with bones, and eggs) or low (seeds and pork) for WRA and low for pregnant women. In addition, several food groups presented moderate iron density for adults, including fresh fish, canned fish without bones, whole grains, and unrefined grain products, whereas they all rated low for both WRA and pregnant women. Finally, for pregnant women, the only top folate sources were liver and pulses, whereas for adults and WRA top sources also included DGLVs and quinoa, with the addition of eggs for WRA and kidney (including beef, lamb, and pork kidney), fonio, and teff for children 2–4 years and adolescents.

Discussion

Our analysis has provided ratings of inherent food sources of multiple and individual micronutrients commonly lacking in diets, especially in LMICs, for population groups with increased needs and the broader adult population. In general, animal-source foods like organs, shellfish, small fish, ruminant meat, eggs, milk, and canned fish with bones are top sources of multiple priority micronutrients. Cheese, goat milk, and pork are also good sources, followed by yogurt and fresh fish. Among plant-source foods, DGLVs are a top source of priority micronutrients, and pulses and teff, a traditional grain, are also decent sources. Interestingly, many foods commonly promoted as nutrient-dense, including most fruits and vegetables, canned fish without bones, nuts and seeds, chicken, and whole grains, are not particularly dense in micronutrients commonly lacking in LMICs. These foods, of course, provide important nutritional benefits beyond these specific nutrients. Indeed, priority micronutrients are just one of many important aspects contributing to overall diet quality, and foods presenting low density in priority micronutrients may be rich in other essential and non-essential beneficial compounds and can contribute to overall energy and protein requirements.

These findings have implications for vegetarian populations, since animal flesh foods are dense in priority micronutrients. In addition to DGLVs, both eggs and dairy foods are excellent sources of priority micronutrients for lacto-ovo vegetarians. Fortunately, eggs and dairy foods are among the more affordable animal-source foods per unit priority nutrient density, although not as affordable as organs and small fish, and they are still often inaccessible or unaffordable for people with limited resources (30,32). Importantly, DGLVs and pulses are accessible and affordable sources of several priority micronutrients in most populations (30,32). Further, traditional grains, including teff, quinoa, fonio, and millet, are at least moderately dense in iron, zinc, and folate and can also make significant contributions to nutrient adequacy. Lacto-ovo vegetarian diets rich in eggs, dairy, DGLVs, pulses, and traditional grains can provide adequate amounts of all six priority micronutrients. Carefully constructed vegan diets could provide adequate amounts of all six priority micronutrients for the general population, except vitamin B_{12}, which would need to be consumed through fortified foods or supplements. However, population groups with increased nutritional requirements, such as pregnant women and children during the complementary feeding period, following a vegan diet might also need fortification or supplementation for other micronutrients, such as iron, in addition to vitamin B_{12}.

Our study has several strengths. The methods are transparent and based on publicly available data, as has been recommended (33,34). The food composition data is comprehensive and representative of diets in diverse contexts globally, unlike existing nutrient profiling systems, which are based solely on national food composition data, typically USDA FDC (33,34), and we adjusted for differences in bioavailability of iron and zinc across foods. Similarly, recommended intakes are based on dietary reference values that are appropriate for global populations, including LMICs, and were calculated for the general adult population as well as groups with increased needs. Our ratings prioritize foods that are optimal sources of micronutrients known to be commonly lacking and causing significant health burdens in LMICs, in alignment with the recommendation to focus nutrient profiling models for LMICs on nutrient density of beneficial nutrients, rather than nutrients to limit (33). Lastly, the results are organized in clear and simple visualizations which are easily interpretable by non-technical audiences, including decision makers.

The primary limitation of our study is that it only focused on inherent priority micronutrient density and bioavailability and does not address the overall role of food and diets in nutrient adequacy, infectious diseases, and NCDs and their broader impact on the global burden of disease (35). Other essential vitamins and minerals, including vitamin C, vitamin E, riboflavin, thiamin, niacin, potassium, and magnesium, can also be lacking in diets, but data is limited on how widespread these inadequacies are and their public health significance (1). Moreover, adequate calories (36), protein (37), and essential amino acids (38) and fatty acids (especially n-3 fatty acids) (39) are also often lacking and critically important for health. Furthermore, there are countless “non-essential” but nonetheless potentially beneficial compounds including fiber, phytonutrients, and bioactive compounds in plant and animal-source foods which play an important role in health and disease (10–12,35). Finally, there are numerous compounds that are associated with increased risk of disease when consumed in excess, including sugar, sodium, trans fat, cosmetic additives, and contamination and biological hazards in unsafe food, among others, for which the type and level of processing often plays an important role (40–42).

In addition to being focused on just one aspect of diet quality, our analysis has other important limitations. First, there are large differences in nutrient densities across food composition databases, which may reflect differences in varieties, production methods, soil conditions, fertilizer use, animal feed quality, culinary traditions, and/or technical and analytical quality of the underlying databases. Moreover, mineral densities have even been shown to vary geospatially within individual countries (43). Since the exact nutrient densities of any given food and context are unknown, we chose to use aggregate values to smooth out these variations, which contributes to the added value of our global food composition database. Second, in addition to significant differences across FCTs, there is sometimes high nutrient-density variance across foods within food groups, meaning that the ranking of a food group as a whole might not reflect the micronutrient density of the most (or least) nutrient-dense foods included. However, we chose to maintain these levels of aggregation because our selected food groups are more likely to be targeted in programming and policies than individual foods and match more closely with food groups in upcoming global diet quality monitoring data (44,45). Third, country and regional FCTs only included a limited set of commonly consumed foods, which limited the breadth of foods included in our aggregated food composition database. For instance, we were unable to analyze many nutrient-dense wild or indigenous vegetables, nuts, seeds, pulses, and insects. Fourth, while we adjusted for bioavailability of iron and zinc, actual bioavailability depends on the genetics and micronutrient status of the individual and their overall diet, including a broad set of enhancers and inhibitors. Finally, ratings are sensitive to categorical thresholds for quantities of calories and grams, which requires some attention when interpreting results, since foods near the thresholds could have been rated differently with only small changes in nutrient densities. Some of the differences in ratings across population groups could thus be due to small differences in nutrient densities for foods near thresholds.

These ratings are most applicable for populations in LMICs suffering from widespread micronutrient deficiencies. However, for population groups with increased needs in HICs, such as women, who may often be deficient in micronutrients such as iron, these results can also help identify relevant foods to prioritize. Importantly, diets should consist of a variety of foods with varying nutrient densities. Even adding just small amounts of particularly nutrient dense animal-source foods (for example, organs and bivalves) to largely plant-based diets would go a long way towards ensuring adequacy of micronutrients commonly lacking. Future analyses should focus on understanding how to use these findings to improve food, agriculture, and nutrition policies and programs, which tend to focus on specific foods or food groups. Researchers could build on this work by incorporating additional foods and food groups, including wild or indigenous vegetables, nuts, seeds, pulses, and insects (46), many of which contain very high nutrient densities (47). Moreover, these ratings could be paired with broader diet quality metrics (45) and included as an additional way to assess food affordability, for example, by expanding on existing approaches (30,32), as has been done for other nutrient profiling systems (48). Finally, these ratings could also be used for environmental impact assessments. While plant-source foods generally have lower negative environmental impacts than animal-source foods per unit protein, energy, or mass (49), this generalization may not hold when considering the higher nutrient density of many animal-source foods. For example, bivalves are dense in all six priority micronutrients and capable of being produced sustainably (50).

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Author contributions
TB and FO designed the study, conducted the analyses, and wrote the paper.

Competing Interests statement
The authors declare no competing interests.

References

1. Beal T, Massiot E, Arsenault JE, Smith MR, Hijmans RJ. Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes. *PLOS ONE* (2017) 12:e0175554. doi:10.1371/journal.pone.0175554

2. Bailey RL, West KP, Black RE. The epidemiology of global micronutrient deficiencies. *Ann Nutr Metab* (2015) 66 Suppl 2:22–33. doi:10.1159/000371618

3. WHO. Vitamin and Mineral Nutrition Information System (VMNIS). Available at: https://www.who.int/teams/nutrition-and-food-safety/databases/vitamin-and-mineral-nutrition-information-system [Accessed June 13, 2021]

4. Beal T, White JM, Arsenault JE, Okronipa H, Hinnouho G-M, Torlesse H, Murira Z, Garg A. Micronutrient gaps during the complementary feeding period in South Asia: A Comprehensive Nutrient Gap Assessment. *Nutrition Reviews* (2021) 79: doi:http://dx.doi.org/10.1093/nutrit/nuaa144

5. White JM, Beal T, Chimanya K, Arsenault JE, Okronipa H, Hinnouho G-M, Garg A, Matji J. Micronutrient gaps during the complementary feeding period in Eastern and Southern Africa: A Comprehensive Nutrient Gap Assessment. *Nutrition Reviews* (2021) 79: doi:http://dx.doi.org/10.1093/nutrit/nuaa142

6. Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, de Onis M, Ezzati M, Grantham-McGregor S, Katz J, Martorell R, et al. Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet* (2013) 382:427–451. doi:10.1016/S0140-6736(13)60937-X

7. Miller EM. Iron Status and Reproduction in US Women: National Health and Nutrition Examination Survey, 1999-2006. *PLOS ONE* (2014) 9:e112216. doi:10.1371/journal.pone.0112216

8. Osendarp SJM, Martinez H, Garrett GS, Neufeld LM, De-Regil LM, Vossenaar M, Darnton-Hill I. Large-Scale Food Fortification and Biofortification in Low- and Middle-Income Countries: A Review of Programs, Trends, Challenges, and Evidence Gaps. *Food Nutr Bull* (2018) 39:315–331. doi:10.1177/0379572118774229

9. Listing Compounds - FooDB. Available at: https://foodb.ca/compounds [Accessed June 13, 2021]

10. van Vliet S, Kronberg SL, Provenza FD. Plant-Based Meats, Human Health, and Climate Change. *Front Sustain Food Syst* (2020) 4: doi:10.3389/fsufs.2020.00128

11. Barabási A-L, Menichetti G, Loscalzo J. The unmapped chemical complexity of our diet. *Nat Food* (2020) 1:33–37. doi:10.1038/s43016-019-0005-1

12. Jacobs DR, Tapsell LC. Food, Not Nutrients, Is the Fundamental Unit in Nutrition. *Nutrition Reviews* (2007) 65:439–450. doi:10.1111/j.1753-4887.2007.tb00269.x

13. Aguilera JM. The food matrix: implications in processing, nutrition and health. *Critical Reviews in Food Science and Nutrition* (2019) 59:3612–3629. doi:10.1080/10408398.2018.1502743

14. Lane MM, Davis JA, Beattie S, Gómez-Donoso C, Loughman A, O'Neil A, Jacka F, Berk M, Page R, Marx W, et al. Ultraprocessed food and chronic noncommunicable diseases: A systematic review and meta-analysis of 43 observational studies. *Obes Rev* (2021) 22:e13146. doi:10.1111/obr.13146

15. Hall KD, Ayuketah A, Brychta R, Cai H, Cassimatis T, Chen KY, Chung ST, Costa E, Courville A, Darcey V, et al. Ultra-Processed Diets Cause Excess Calorie Intake and Weight Gain: An Inpatient Randomized Controlled Trial of Ad Libitum Food Intake. *Cell Metabolism* (2019) 30:67-77.e3. doi:10.1016/j.cmet.2019.05.008

16. European Food Safety Authority (EFSA). Dietary Reference Values for nutrients Summary report. *EFSA Supporting Publications* (2017) 14:e15121E. doi:10.2903/sp.efsa.2017.e15121

17. Institute of Medicine Committee to Review Dietary Reference Intakes for Vitamin D and Calcium. *Dietary Reference Intakes for Calcium and Vitamin D.* , eds. A. C. Ross, C. L. Taylor, A. L. Yaktine, H. B. Del Valle Washington, DC: National Academies Press (2011).

18. Allen LH, Carriquiry AL, Murphy SP. Perspective: Proposed Harmonized Nutrient Reference Values for Populations. *Adv Nutr* (2020) 11:469–483. doi:10.1093/advances/nmz096

19. FAO/IZiNCG. *FAO/INFOODS/IZiNCG Global Food Composition Database for Phytate Version 1.0 - PhyFoodComp 1.0*. Rome, Italy. (2018). Available at: http://www.fao.org/3/i8542en/I8542EN.pdf

20. U.S. DEPARTMENT OF AGRICULTURE (USDA), Agricultural Research Service. USDA FoodData Central. Available at: https://fdc.nal.usda.gov/ [Accessed June 18, 2021]

21. FAO. INFOODS: FAO/INFOODS Databases. Available at: http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/ [Accessed June 18, 2021]

22. Valenzuela C, López de Romaña D, Olivares M, Morales MS, Pizarro F. Total Iron and Heme Iron Content and their Distribution in Beef Meat and Viscera. *Biol Trace Elem Res* (2009) 132:103–111. doi:10.1007/s12011-009-8400-3

23. Balder HF, Vogel J, Jansen MCJF, Weijenberg MP, van den Brandt PA, Westenbrink S, van der Meer R, Goldbohm RA. Heme and chlorophyll intake and risk of colorectal cancer in the Netherlands cohort study. *Cancer Epidemiol Biomarkers Prev* (2006) 15:717–725. doi:10.1158/1055-9965.EPI-05-0772

24. Total Heme and Non-heme Iron in Raw and Cooked Meats - Lombardi-Boccia - 2002 - Journal of Food Science - Wiley Online Library. Available at:

https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2621.2002.tb08715.x [Accessed June 18, 2021]

25. Pourkhalili A, Mirlohi M, Rahimi E. Heme Iron Content in Lamb Meat Is Differentially Altered upon Boiling, Grilling, or Frying as Assessed by Four Distinct Analytical Methods. *The Scientific World Journal* (2013) 2013:e374030. doi:10.1155/2013/374030

26. Kabat GC, Miller AB, Jain M, Rohan TE. A cohort study of dietary iron and heme iron intake and risk of colorectal cancer in women. *Br J Cancer* (2007) 97:118–122. doi:10.1038/sj.bjc.6603837

27. Ronco A, Espinosa E, Calderon J. A case-control study on heme/non-heme iron and breast cancer risk 1 MedDocs Publishers of Creative Commons Attribution 4.0 International License Annals of Clinical Nutrition. (2018)

28. Kongkachuichai R, Napatthalung P, Charoensiri R. Heme and Nonheme Iron Content of Animal Products Commonly Consumed in Thailand. *Journal of Food Composition and Analysis* (2002) 15:389–398. doi:10.1006/jfca.2002.1080

29. Taniguchi CN, Dobbs J, Dunn MA. Heme iron, non-heme iron, and mineral content of blood clams (Anadara spp.) compared to Manila clams (V. philippinarum), Pacific oysters (C. gigas), and beef liver (B. taurus). *Journal of Food Composition and Analysis* (2017) 57:49–55. doi:10.1016/j.jfca.2016.12.018

30. Ryckman T, Beal T, Nordhagen S, Chimanya K, Matji J. Affordability of nutritious foods for complementary feeding in Eastern and Southern Africa. *Nutrition Reviews* (2021) 79:

31. Hall KD, Guo J, Courville AB, Boring J, Brychta R, Chen KY, Darcey V, Forde CG, Gharib AM, Gallagher I, et al. Effect of a plant-based, low-fat diet versus an animal-based, ketogenic diet on ad libitum energy intake. *Nat Med* (2021) 27:344–353. doi:10.1038/s41591-020-01209-1

32. Ryckman T, Beal T, Nordhagen S, Murira Z, Torlesse H. Affordability of nutritious foods for complementary feeding in South Asia. *Nutrition Reviews* (2021) 79:

33. Miller GD, Drewnowski A, Fulgoni V, Heaney RP, King J, Kennedy E. It Is Time for a Positive Approach to Dietary Guidance Using Nutrient Density as a Basic Principle. *The Journal of Nutrition* (2009) 139:1198–1202. doi:10.3945/jn.108.100842

34. Drewnowski A, Amanquah D, Gavin-Smith B. Perspective: How to Develop Nutrient Profiling Models Intended for Global Use: A Manual. *Advances in Nutrition* (2021) 12:609–620. doi:10.1093/advances/nmab018

35. Afshin A, Sur PJ, Fay KA, Cornaby L, Ferrara G, Salama JS, Mullany EC, Abate KH, Abbafati C, Abebe Z, et al. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet* (2019) 0: doi:10.1016/S0140-6736(19)30041-8

36. FAO, IFAD, UNICEF, WFP, WHO. *The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets*. Rome, Italy: FAO, IFAD, UNICEF, WFP and WHO (2020). doi:10.4060/ca9692en

37. Wu G, Fanzo J, Miller DD, Pingali P, Post M, Steiner JL, Thalacker-Mercer AE. Production and supply of high-quality food protein for human consumption: sustainability, challenges, and innovations. *Annals of the New York Academy of Sciences* (2014) 1321:1–19. doi:10.1111/nyas.12500

38. Semba RD, Shardell M, Sakr Ashour FA, Moaddel R, Trehan I, Maleta KM, Ordiz MI, Kraemer K, Khadeer MA, Ferrucci L, et al. Child Stunting is Associated with Low Circulating Essential Amino Acids. *EBioMedicine* (2016) 6:246–252. doi:10.1016/j.ebiom.2016.02.030

39. Simopoulos AP. Essential fatty acids in health and chronic disease. *The American Journal of Clinical Nutrition* (1999) 70:560s–569s. doi:10.1093/ajcn/70.3.560s

40. Mozaffarian Dariush. Dietary and Policy Priorities for Cardiovascular Disease, Diabetes, and Obesity. *Circulation* (2016) 133:187–225. doi:10.1161/CIRCULATIONAHA.115.018585

41. Neufeld LM, Hendriks S, Hugas M. Healthy diet: A definition for the United Nations Food Systems Summit 2021. (2020)

42. Monteiro CA, Cannon G, Levy RB, Moubarac J-C, Louzada ML, Rauber F, Khandpur N, Cediel G, Neri D, Martinez-Steele E, et al. Ultra-processed foods: what they are and how to identify them. *Public Health Nutrition* (2019) 22:936–941. doi:10.1017/S1368980018003762

43. Gashu D, Nalivata PC, Amede T, Ander EL, Bailey EH, Botoman L, Chagumaira C, Gameda S, Haefele SM, Hailu K, et al. The nutritional quality of cereals varies geospatially in Ethiopia and Malawi. *Nature* (2021) 594:71–76. doi:10.1038/s41586-021-03559-3

44. Herforth AW, Wiesmann D, Martínez-Steele E, Andrade G, Monteiro CA. Introducing a Suite of Low-Burden Diet Quality Indicators That Reflect Healthy Diet Patterns at Population Level. *Current Developments in Nutrition* (2020) 4: doi:10.1093/cdn/nzaa168

45. Herforth A, Beal T, Rzepa A. Global Diet Quality Project Aims to Bridge Data Gap. *Gallup.com* (2020) Available at: https://news.gallup.com/opinion/gallup/321968/global-diet-quality-project-aims-bridge-data-gap.aspx [Accessed June 29, 2021]

46. Smith MR, Stull VJ, Patz JA, Myers SS. Nutritional and environmental benefits of increasing insect consumption in Africa and Asia. *Environ Res Lett* (2021) 16:065001. doi:10.1088/1748-9326/abf06c

47. Nyirenda D, Musukwa M, Mugode R, Shindano J. Zambia Food Composition Tables, 4th Edition. Lusaka, Zambia: National Food and Nutrition Commission (2009). Available at:

https://www.nfnc.org.zm/download/zambia-food-composition-tables-4th-edition/ [Accessed June 29, 2021]

48. Drewnowski A, Smith J, Fulgoni VL. The New Hybrid Nutrient Density Score NRFh 4:3:3 Tested in Relation to Affordable Nutrient Density and Healthy Eating Index 2015: Analyses of NHANES Data 2013–16. *Nutrients* (2021) 13:1734. doi:10.3390/nu13051734

49. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. *Science* (2018) 360:987–992. doi:10.1126/science.aaq0216

50. Wijsman JWM, Troost K, Fang J, Roncarati A. "Global Production of Marine Bivalves. Trends and Challenges," in *Goods and Services of Marine Bivalves*, eds. A. C. Smaal, J. G. Ferreira, J. Grant, J. K. Petersen, Ø. Strand (Cham: Springer International Publishing), 7–26. doi:10.1007/978-3-319-96776-9_2

Table 1 | Recommended nutrient intakes for select groups

Group	AER (kcal)	Vit A (mcg RAE)	Folate (mcg DFE)	Vit B_{12} (mcg)	Calcium (mg)	Iron (mg)[1]			Zinc (mg)[2]			
						20%	15%	10%	R	SR	SU	U
Children 2–4	1246	230	128	1.0	590	7.4	9.8	14.8	3.2	3.9	4.7	5.5
Adolescents 10–19	2296	632	292	2.2	1085	9.9	13.2	19.8	8.3	9.9	11.4	13.0
Women 15–49	2305	637	325	2.4	977	15.9	21.2	31.8	8.0	9.6	11.1	12.6
Pregnant women 15–49	2583	700	600	2.6	977	24.3	32.4	48.6	9.1	10.9	12.6	14.3
Adults 25+[3]	2227	694	328	2.4	950	7.0	10.0	14.0	9.4	11.7	14.0	16.3

Average energy requirements for a moderately active individual and recommended intakes for vitamin A, folate, calcium and zinc from the European Food Safety Authority (16). Recommended intakes for iron and vitamin B_{12} from the Institute of Medicine (17). [1]Percentages represent different levels of bioavailability that correspond with the possible classifications of each food in the analysis. [2]Assuming 300 mg phytate/day and 44% absorption for refined (R) diets, 600 mg phytate/day and 35% absorption for semi-refined (SR) diets, 900 mg phytate/day and 30% absorption for semi-unrefined (SU) diets, and 1200 mg phytate/day and 26% absorption for unrefined (U) diets. [3]Includes both men and women. AER, Average Energy Requirement; DFE, dietary folate equivalent; R, refined; RAE, retinol activity equivalent; SR, semi-refined; SU, semi-unrefined; U, unrefined; Vit, vitamin.

Table 2 | Global food composition database

Food (100 g)	kcal	Vit A (mcg RAE)	Folate (mcg DFE)	Vit B_{12} (mcg)	Calcium (mg)	Iron (mg)	Zinc (mg)	Iron Abs	Zinc Abs	Phytate (mg)
Pulses	134	1	88	0	29	2.4	1.2	0.10	0.26	441
Whole grains[1,9]	204	0	16	0	22	1.9	1.5	0.10	0.26	510
Refined grains[9]	133	0	5	0	9	0.5	0.6	0.10	0.44	45
Unrefined grain products[2,9]	166	2	31	0	29	1.9	1.0	0.10	0.30	129
Refined grain products[9]	168	0	12	0	12	0.8	0.5	0.10	0.44	49
Sorghum[3]	142	0	20	0	9	2.6	0.8	0.10	0.26	272
Millet	148	0	27	0	10	2.6	1.0	0.10	0.26	200
Teff[4,5]	149	0	42	0	49	4.3	1.1	0.10	0.26	284
Fonio[3,4]	139	1	36	0	12	2.8	1.1	0.10	0.30	110
Quinoa[6]	115	0	43	0	17	2.0	1.0	0.10	0.26	554
Roots, tubers, plantains	111	14	12	0	17	0.7	0.3	0.10	0.44	13
Nuts	594	0	72	0	62	4.1	3.0	0.10	0.26	670
Seeds	579	1	98	0	333	7.6	5.5	0.10	0.26	653
Dark green leafy vegetables	30	252	57	0	148	2.2	0.4	0.10	0.44	17
Vitamin A-rich fruits/vegetables	40	124	24	0	20	0.5	0.2	0.10	0.44	24
Other vegetables	28	20	17	0	18	0.5	0.2	0.10	0.44	10
Other fruits	65	4	19	0	11	0.4	0.2	0.10	0.44	10
Eggs	156	163	45	1.1	50	1.6	1.1	0.15	0.44	0
Fresh cow milk	67	44	5	0.4	120	0.1	0.4	0.15	0.44	0
Cooked cow milk	61	39	5	0.5	116	0.1	0.5	0.15	0.44	0
Fresh goat milk	72	35	1	0.1	143	0.1	0.3	0.15	0.44	0
Yoghurt	77	27	7	0.4	121	0.1	0.4	0.15	0.44	0
Cheese	359	213	16	1.0	707	0.5	3.0	0.15	0.44	0
Beef	217	3	4	2.1	8	2.5	5.8	0.20	0.44	0
Goat	146	0	3	1.2	17	3.2	5.0	0.20	0.44	0
Lamb/mutton	290	0	9	2.5	14	2.0	4.7	0.20	0.44	0
Pork	242	2	3	0.7	23	1.6	2.6	0.15	0.44	0
Chicken	229	29	6	0.3	14	1.0	1.5	0.15	0.44	0
Beef liver	177	8645	257	76.2	7	9.0	5.2	0.15	0.44	0
Goat/lamb liver[4]	207	18093	349	85.6	11	10.0	6.3	0.15	0.44	0
Chicken liver	141	3492	534	16.1	10	10.3	3.4	0.15	0.44	0
Pork liver[7]	114	4796	148	15.8	10	17.9	4.6	0.15	0.44	0
Heart[7]	112	4	25	5.1	7	4.4	3.1	0.15	0.44	0
Spleen[6]	114	0	3	4.2	10	35.8	2.5	0.15	0.44	0

Kidney	97	69	34	14.5	12	5.6	2.4	0.15	0.44	0
Fresh fish[10]	123	10	10	1.8	39	0.8	0.7	0.15	0.44	0
Small dried fish[4]	294	186	37	12.1	2360	10.0	10.2	0.15	0.44	0
Canned fish, without bones[8]	153	14	5	2.2	12	1.3	0.6	0.15	0.44	0
Canned fish, with bones[8]	201	40	9	5.8	252	2.3	1.4	0.15	0.44	0
Crustaceans	89	8	12	1.3	74	1.2	2.2	0.15	0.44	0
Bivalves	87	77	19	23.5	113	4.8	3.6	0.15	0.44	0

[1]Only one food item available for the South and South East Asia; [2]No foods available for the South and South East Asia; [3]No values available from FoodData Central; [4]Values available for Sub-Saharan African only. Additional values from the literature used; [5]for zinc absorption, used average phytate of the four other traditional grains (sorghum, millet, fonio, quinoa); [6]Values available for Latin America only; [7]Values available for South and South East Asia and Latin American only; [8]Values available for Sub-Saharan Africa and Latin America only. [9]The term "grains" (both whole and refined) refers to cereal grains, such as wheat, rice, oats, and barley. The term "grain products" (both unrefined and refined) refers to products obtained from flours, requiring some additional processing, such as breads, pasta, and noodles. [10]Aggregate group including different species of marine and freshwater fish. Abs, absorption; Vit, vitamin.

Figure Legends

Figure 1 | Calories and grams needed to provide an average of one-third of recommended intakes of vitamin A, folate, vitamin B_{12}, calcium, iron, and zinc for women of reproductive age. Each micronutrient's contribution is capped at 100% of recommended intakes. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

Figure 2 | Aggregate and individual micronutrient density scores for women of reproductive age. prod, products; veg, vegetables.

Figure 3 | Calories and grams needed to provide one-third of recommended iron intakes for women of reproductive age. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

Figure 4 | Calories and grams needed to provide an average of one-third of recommended intakes of vitamin A, folate, vitamin B_{12}, calcium, iron, and zinc for adults ≥ 25. Each nutrient's contribution is capped at 100% of recommended intakes. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

Figure 5 | Aggregate and individual micronutrient density scores for adults ≥ 25. Mod, Moderate; prod, products; veg, vegetables.

Figure 6 | Calories and grams needed to provide one-third of recommended iron intakes for adults ≥ 25. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

Figures

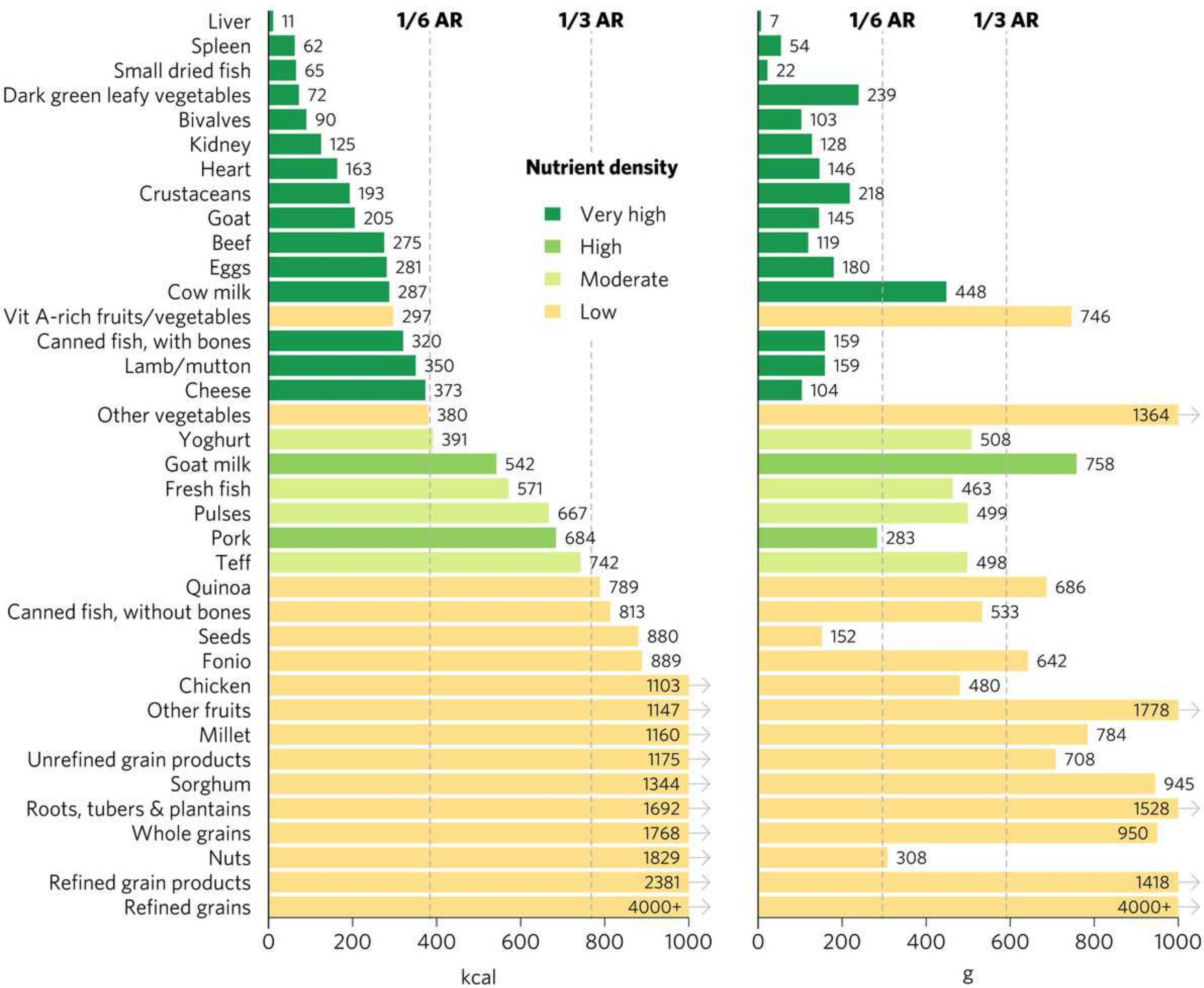

Figure 1

Calories and grams needed to provide an average of one-third of recommended intakes of vitamin A, folate, vitamin B12, calcium, iron, and zinc for women of reproductive age. Each micronutrient's contribution is capped at 100% of recommended intakes. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

	2+ nutrients	Iron	Zinc	Vitamin A	Calcium	Folate	Vitamin B_{12}
Liver	Very high	Very high	Very high	Very high	Low	Very high	Very high
Spleen	Very high	Very high	Very high	Low	Low	Low	Very high
Small dried fish	Very high	Very high	Very high	Very high	Very high	Low	Very high
Dark leafy greens	Very high	High	Low	Very high	Very high	Very high	Low
Bivalves	Very high	Very high	Very high	Very high	Very high	Moderate	Very high
Kidney	Very high	Very high	Very high	High	Low	High	Very high
Heart	Very high	Very high	Very high	Low	Low	Moderate	Very high
Crustaceans	Very high	Moderate	Very high	Low	Moderate	Low	Very high
Goat	Very high	Very high	Very high	Low	Low	Low	Very high
Beef	Very high	High	Very high	Low	Low	Low	Very high
Eggs	Very high	Moderate	Very high	Very high	Low	Very high	Very high
Cow milk	Very high	Low	High	Very high	Very high	Low	Very high
Canned fish w/ bones	Very high	Moderate	Very high	Low	Very high	Low	Very high
Lamb/mutton	Very high	High	Very high	Low	Low	Low	Very high
Cheese	Very high	Low	Very high	Very high	Very high	Low	Very high
Goat milk	High	Low	Moderate	High	Very high	Low	Low
Pork	High	Low	Very high	Low	Low	Low	Very high
Yoghurt	Moderate	Low	Low	Low	Very high	Low	Very high
Fresh fish	Moderate	Low	Moderate	Low	Low	Low	Very high
Pulses	Moderate	Moderate	Moderate	Low	Low	Very high	Low
Teff	Moderate	Very high	Moderate	Low	Low	High	Low
Vit A-rich fruit/veg	Low	Low	Low	Very high	Low	High	Low
Other vegetables	Low	Low	Low	Low	Low	Low	Low
Quinoa	Low	Moderate	Moderate	Low	Low	Very high	Low
Canned fish w/o bones	Low	Low	Moderate	Low	Low	Low	Very high
Seeds	Low	Low	High	Low	High	High	Low
Fonio	Low	Moderate	Moderate	Low	Low	Moderate	Low
Chicken	Low	Low	High	Low	Low	Low	High
Other fruits	Low	Low	Low	Low	Low	High	Low
Millet	Low	Moderate	Moderate	Low	Low	Moderate	Low
Unrefined grain prod	Low	Low	Moderate	Low	Low	Moderate	Low
Sorghum	Low	Moderate	Low	Low	Low	Low	Low
Roots/tubers/plantains	Low	Low	Low	Low	Low	Low	Low
Whole grains	Low	Low	Moderate	Low	Low	Low	Low
Nuts	Low	Low	Low	Low	Low	Low	Low
Refined grain products	Low	Low	Low	Low	Low	Low	Low
Refined grains	Low	Low	Moderate	Low	Low	Low	Low

Figure 2

Aggregate and individual micronutrient density scores for women of reproductive age. prod, products; veg, vegetables.

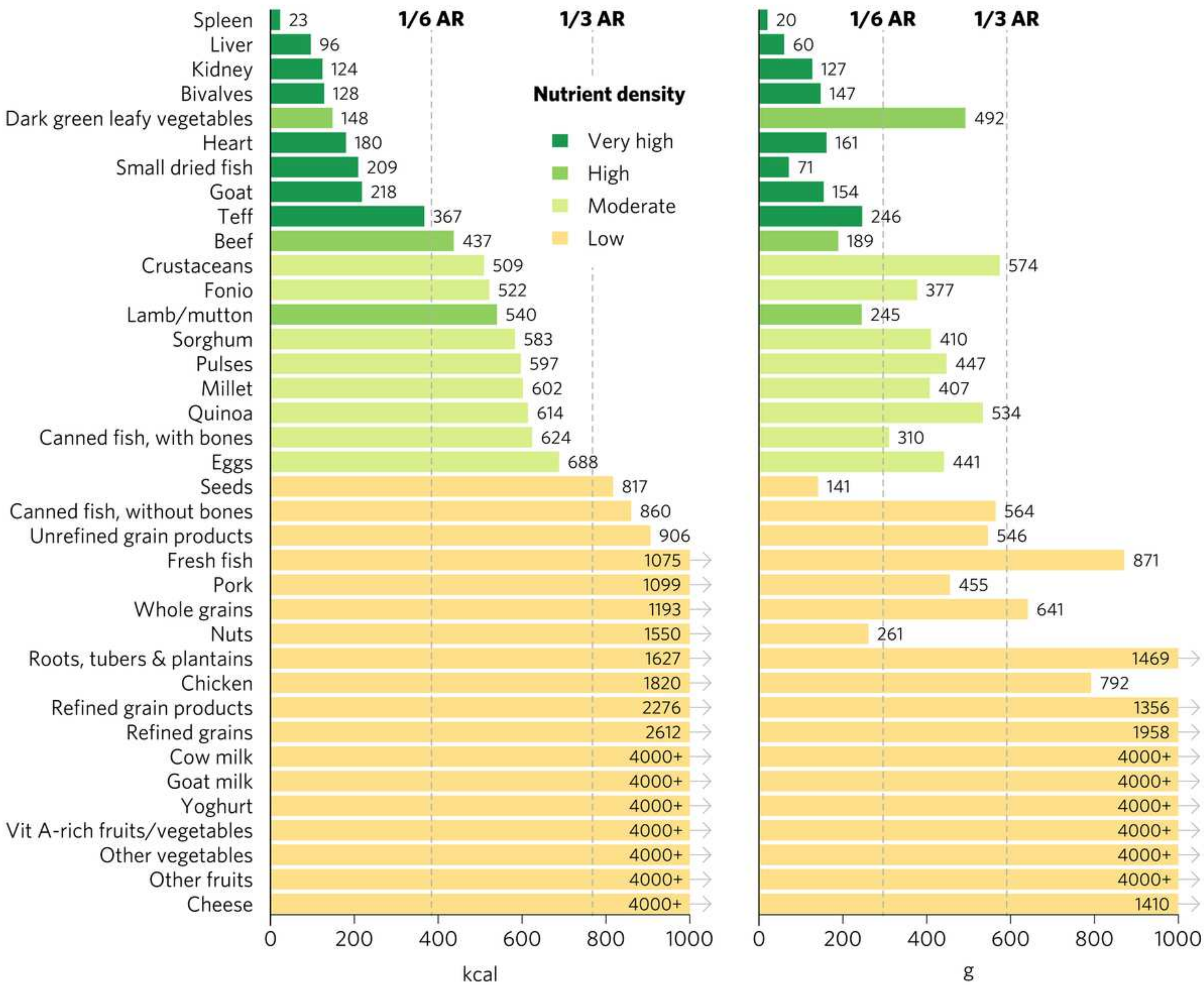

Figure 3

Calories and grams needed to provide one-third of recommended iron intakes for women of reproductive age. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

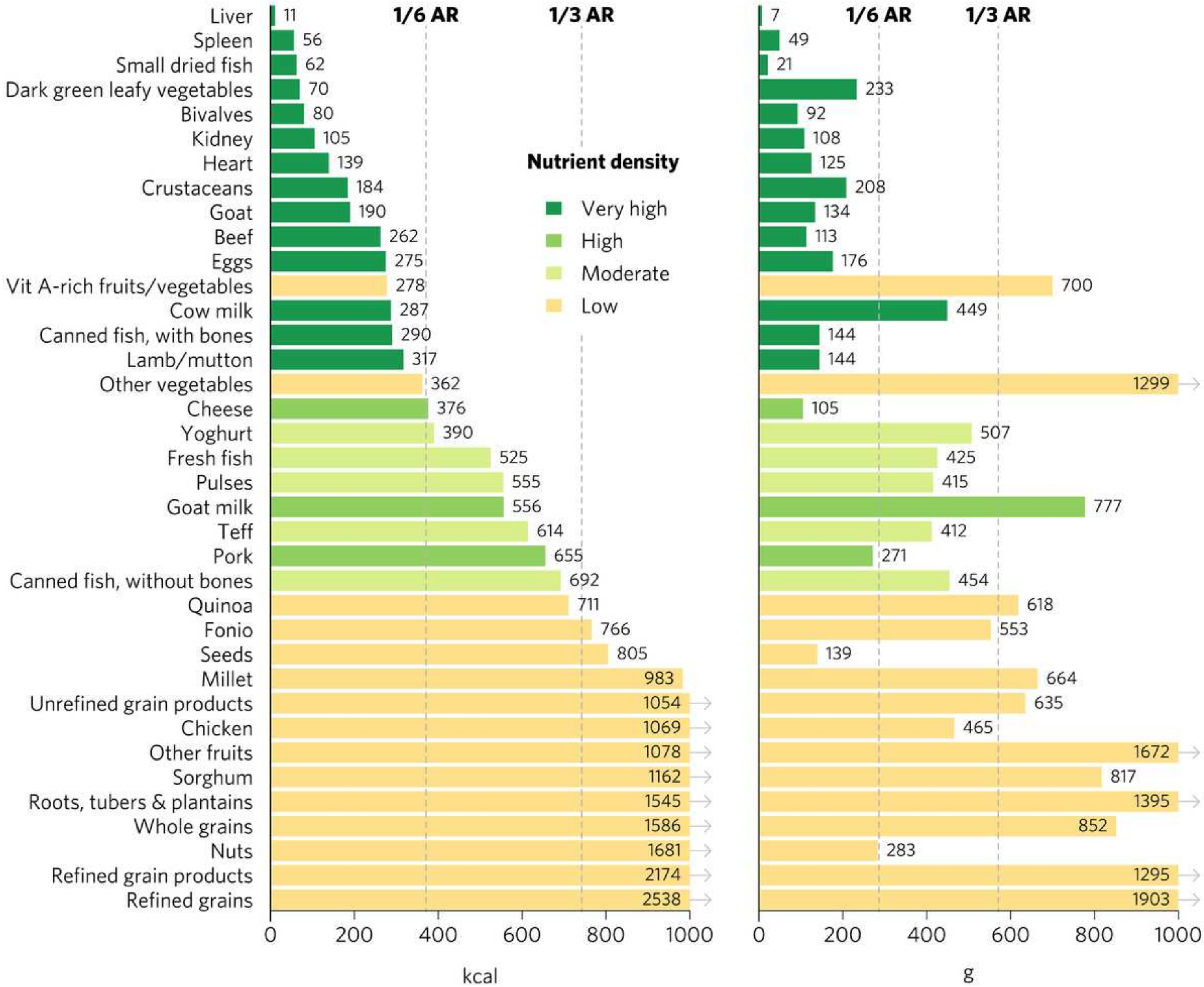

Figure 4

Calories and grams needed to provide an average of one-third of recommended intakes of vitamin A, folate, vitamin B12, calcium, iron, and zinc for adults ≥ 25. Each nutrient's contribution is capped at 100% of recommended intakes. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

	2+ nutrients	Iron	Zinc	Vitamin A	Calcium	Folate	Vitamin B_{12}
Liver	Very high	Very high	Very high	Very high	Low	Very high	Very high
Spleen	Very high	Very high	Very high	Low	Low	Low	Very high
Small dried fish	Very high	Very high	Very high	Very high	Very high	Low	Very high
Dark leafy greens	Very high	High	Low	Very high	Very high	Very high	Low
Bivalves	Very high	Very high	Very high	High	Very high	Moderate	Very high
Kidney	Very high	Very high	Very high	High	Low	High	Very high
Heart	Very high	Very high	Very high	Low	Low	Moderate	Very high
Crustaceans	Very high	High	Very high	Low	Moderate	Low	Very high
Goat	Very high	Very high	Very high	Low	Low	Low	Very high
Beef	Very high	Very high	Very high	Low	Low	Low	Very high
Eggs	Very high	High	High	Very high	Low	High	Very high
Cow milk	Very high	Low	High	Very high	Very high	Low	Very high
Canned fish w/ bones	Very high	High	High	Low	Very high	Low	Very high
Lamb/mutton	Very high	Very high	Very high	Low	Low	Low	Very high
Cheese	High	Low	Very high	High	Very high	Low	Very high
Goat milk	High	Low	Moderate	High	Very high	Low	Low
Pork	High	High	Very high	Low	Low	Low	Very high
Yoghurt	Moderate	Low	Low	Low	Very high	Low	Very high
Fresh fish	Moderate	Moderate	Moderate	Low	Low	Low	Very high
Pulses	Moderate	Very high	Moderate	Low	Low	Very high	Low
Teff	Moderate	Very high	Moderate	Low	Low	High	Low
Canned fish w/o bones	Moderate	Moderate	Moderate	Low	Low	Low	Very high
Vit A-rich fruit/veg	Low	Low	Low	Very high	Low	High	Low
Other vegetables	Low	Low	Low	Low	Low	Low	Low
Quinoa	Low	High	Moderate	Low	Low	Very high	Low
Fonio	Low	Very high	Moderate	Low	Low	Moderate	Low
Seeds	Low	High	High	Low	High	High	Low
Millet	Low	Very high	Moderate	Low	Low	Moderate	Low
Unrefined grain prod	Low	Moderate	Moderate	Low	Low	Moderate	Low
Chicken	Low	Low	High	Low	Low	Low	Moderate
Other fruits	Low	Low	Low	Low	Low	Low	Low
Sorghum	Low	Very high	Low	Low	Low	Low	Low
Roots/tubers/plantains	Low	Low	Low	Low	Low	Low	Low
Whole grains	Low	Moderate	Low	Low	Low	Low	Low
Nuts	Low	Low	Low	Low	Low	Low	Low
Refined grain products	Low	Low	Low	Low	Low	Low	Low
Refined grains	Low	Low	Moderate	Low	Low	Low	Low

Figure 5

Aggregate and individual micronutrient density scores for adults ≥ 25. Mod, Moderate; prod, products; veg, vegetables.

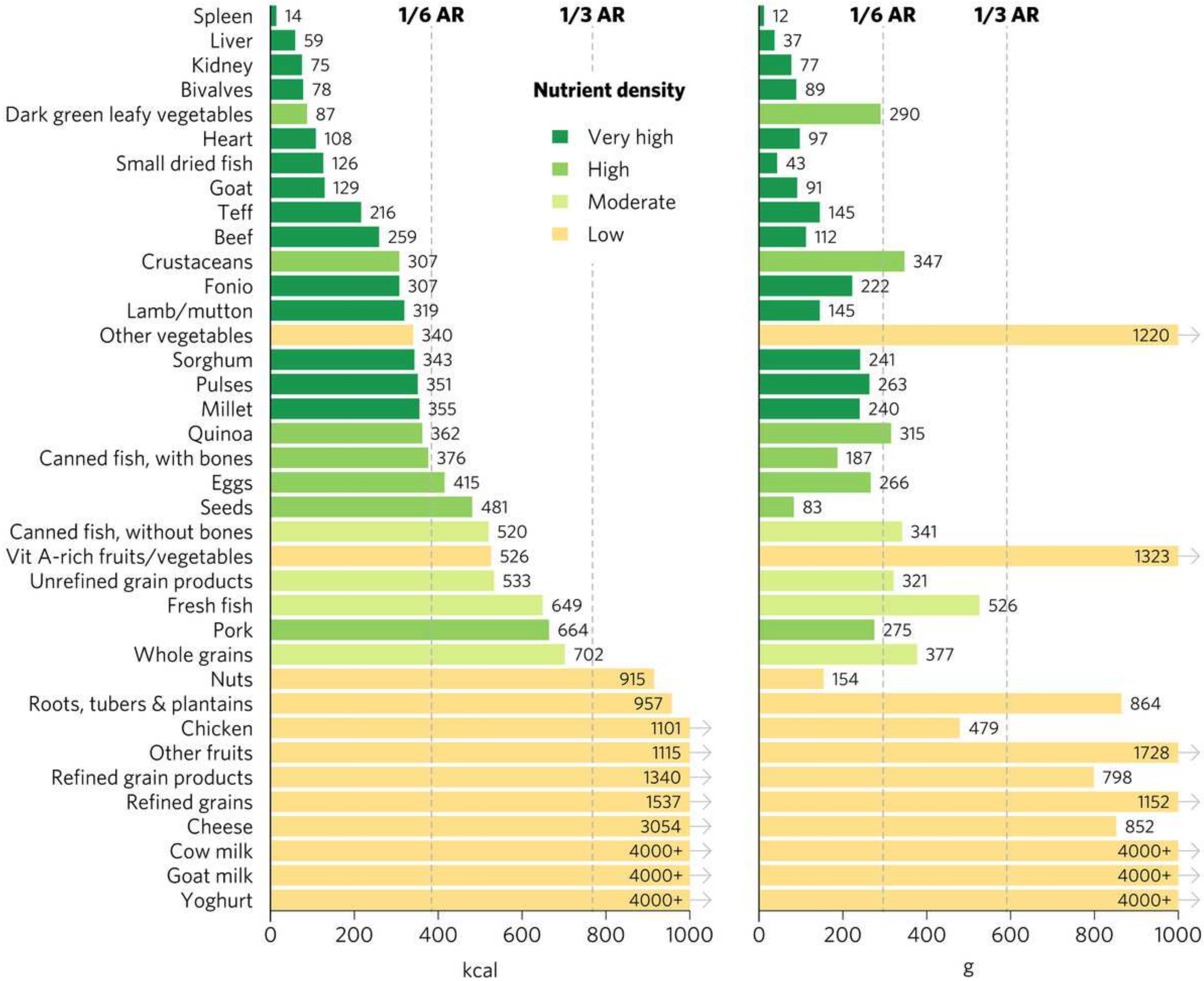

Figure 6

Calories and grams needed to provide one-third of recommended iron intakes for adults ≥ 25. Hypothetical average requirements for mass are based on an energy density of 1.3 kcal/g. AR, average requirement; Vit, vitamin.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

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